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CELLULAR RADIO SYSTEMS AND METHODS FOR THEIR OPERATION

Field of Invention

5 This invention relates to cellular radio systems and to methods for their operation. More particularly, the invention relates to cellular radio systems having increased capacity, and to methods for operating such systems.

10

Background of the Invention

Conventional cellular radio systems comprise a plurality of base stations, each of which serves terminals in a respective geographic area known as a cell. The base stations are interconnected by one or more telecommunications switches. Each base station has a plurality of frequency division multiplexed traffic channels for communication with terminals in its respective cell. Upon receiving a service request from a terminal on a control channel, a base station allocates one of its traffic channels for communication with the terminal. The allocated traffic channel is returned to a pool of unallocated traffic channels when it is no longer needed for communication with the terminal.

25

To avoid interference between terminals and base stations in adjacent cells, traffic channels are assigned to base stations according to a frequency plan such that adjacent base stations have traffic channels operating at different frequencies. Traffic channels are "re-used" at a "re-use rate" of once in every N cells, where N is typically 4, 7 or 12 in commonly used frequency plans.

Time Division Multiplexing (TDM) and Code Division Multiplexing (CDM) techniques have been used to provide multiple traffic channels on each frequency division multiplexed channel, thereby increasing the number

of traffic channels available in each cell. However, even with these techniques, the demand for cellular radio services in a particular cell may grow enough that the maximum number of traffic channels available within re-use limitations in that cell are inadequate to meet the demand.

When this happens, additional base stations may be provided to divide the cell into smaller cells. Each additional base station may have an antenna configuration which causes each of the smaller cells to approximate an ideal hexagonal cell which is smaller than the original cell. Alternatively, the base stations may be provided with directional antennas to divide the original cell into pie-shaped sectors.

According to another capacity enhancement technique, microcells are defined within cells at locations within the original cell where the demand for cellular radio services is particularly high. Each microcell is served by a low power base station to which some of the traffic channels of the cell containing the microcell are assigned. The microcell traffic channels can be used in more than one microcell to increase the re-use rate of at least some of the traffic channels.

Each of the cell division techniques described above requires that additional base stations or directional antennas be provided for capacity enhancement via cell division or sectorization.

Summary of Invention

An object of this invention is to provide capacity enhancement through cell division without necessarily requiring additional base stations or additional directional antennas.

To that end, one aspect of the invention provides a cellular radio system comprising a plurality of base stations, each base station having a first group of channels having a first re-use rate and a second group of channels having a second re-use rate less than the first re-use rate. The cellular radio system is operable upon receipt of a service request for communication with a radio terminal to monitor a parameter indicative of transmission performance between the terminal and one of the base stations of a channel of the first group of channels of the base station. When the monitored parameter indicates adequate transmission performance on the channel of the first group of channels and a channel of the first group of channels is available, the cellular radio system allocates a channel of the first group of channels to the terminal. When the monitored parameter indicates inadequate transmission performance on the channel of the first group of channels and a channel of the second group of channels is available, the cellular radio system allocates a channel of the second group of channels to the terminal. When the monitored parameter indicates adequate performance on the channel of the first group of channels but no channel of the first group of channels is available, the cellular radio system allocates a channel of the second group of channels to the terminal.

(Throughout this specification, the term "re-use rate" refers to the rate at which channels are assigned to cells. For example, if a channel is re-used once in every seventh cell, the re-use rate of that channel is 1/7.)

The relatively high re-use rate of the first group of channels in the cellular radio system as described above enables the system to carry more traffic than a system having a common re-use rate for all channels. Moreover, the allocation of channels of the second group when no channels of the first group are available, further

increases the capacity of the system under some heavy traffic conditions.

5 The cellular radio system may monitor a transmission parameter on a control channel between the terminal and the base station and infer from the monitored parameter whether transmission performance would be adequate on a channel of the first group of channels.

10 Alternatively, the cellular radio system may allocate a channel of the first group of channels to the terminal when at least one channel of the first group is available and monitor a parameter indicative of transmission performance on the allocated channel. The
15 cellular radio system may then re-allocate a channel of the second group of channels to the terminal when the monitored parameter indicates inadequate performance on the allocated channel.

20 The monitored parameter may be indicative of a signal strength of a radio signal received by the base station. In this case, the cellular radio system may allocate a channel of the first group of channels when the monitored parameter is greater than a threshold value and a
25 channel of the first group of channels is available, and may allocate a channel of the second group of channels when the monitored parameter is less than the threshold value. The channels of the first group of channels may be operated at a first power level. The channels of the second group
30 of channels may be operated at the first power level when allocated in response to no channels of the first group of channels being available and the monitored parameter is greater than the threshold value. However, the channels of the second group of channels may be operated at a second
35 power level greater than the first power level when the monitored parameter is less than the threshold value.

Alternatively, the monitored parameter may be indicative of a signal quality of a signal received by the base station from the terminal. For example, the monitored parameter may be a carrier-to-interference ratio or a bit error rate. In this case, the cellular radio system may allocate a channel of the first group of channels to the terminal when the monitored parameter is less than a threshold value and at least one channel of the first group is available and may allocate a channel of the second group of channels to the terminal when the monitored parameter is greater than a threshold value.

One or more of the base stations may serve sectorized cells. In this case, the first and second groups of channels are subdivided into a plurality of subgroups, and each subgroup is allocated to a respective sector of each cell.

Another aspect of the invention provides a method for operating a cellular radio system, the cellular radio system comprising a plurality of base stations, each base station having a first group of channels having a first re-use rate and a second group of channels having a second re-use rate less than the first re-use rate. The method comprises responding to receipt of a service request for communication with a radio terminal by monitoring a parameter indicative of transmission performance between the terminal and one of the base stations of a channel of the first group of channels of the base station, and allocating a channel of the first group of channels to the terminal when the monitored parameter indicates adequate transmission performance on the channel of the first group of channels and a channel of the first group of channels is available. The method further comprises allocating a channel of the second group of channels to the terminal when the monitored parameter indicates inadequate transmission performance on the channel of the first group

of channels when a channel of the second group of channels is available. The method also comprises allocating a channel of the second group of channels to the terminal when the monitored parameter indicates adequate performance on the channel of the first group of channels but no channel of the first group of channels is available.

Yet another aspect of the invention provides a method for operating a cellular radio system which comprises a plurality of base stations, each base station having a first group of channels having a first re-use rate and a second group of channels having a second re-use rate less than the first re-use rate. The method comprises responding to receipt of a service request for communication with a terminal by allocating a channel of the second group of channels to the terminal when a channel of the second group of channels is available. A parameter indicative of transmission performance between the terminal and one of the base stations of a channel of the first group of channels is monitored and a channel of the first group of channels is allocated to the terminal when the monitored parameter indicates adequate transmission performance on the channel of the first group of channels and no channel of the second group of channels is available.

Brief Description of Drawings

Embodiments of the invention are described below by way of example only. Reference is made to accompanying drawings in which:

Figure 1 is a block schematic diagram of a cellular radio system according to an embodiment of the invention;

Figure 2 is a cell map illustrating a frequency re-use plan for idealized hexagonal cells of the cellular radio system of Figure 1;

Figures 3A, 3B and 3C are a flow chart illustrating steps in a channel allocation algorithm according to a first embodiment of the invention;

Figures 4A, 4B and 4C are a flow chart
5 illustrating steps in a channel allocation algorithm according to a second embodiment of the invention;

Figure 5 is a cell map illustrating a frequency re-use plan for idealized tri-sectored hexagonal cells;

Figures 6A and 6B are a flow chart illustrating
10 steps in a channel allocation algorithm used under a first set of conditions according to a third embodiment of the invention;

Figures 7A and 7B are a flow chart illustrating steps in a channel allocation algorithm used under a second
15 set of conditions according to the third embodiment of the invention; and

Figure 8 is a flow chart illustrating steps in a channel allocation algorithm used under a third set of conditions according to the third embodiment of the
20 invention.

Detailed Description

Figure 1 is a block schematic view of a cellular radio system 100 according to a first embodiment of the
25 invention. The cellular radio system 100 comprises one or more radio telephone switching systems 110 interconnected by trunks 120, and a plurality of base stations 130 each of which is connected to one of the switching systems 110 by a transmission facility 140. Each base station 130 serves
30 radio telephones 150 in a respective cell 160.

A switching system 110 of the cellular radio system 100 is connected to a switching system 210 of a Public Switched Telephone Network (PSTN) 200 via a trunk
35 220, so that telephones 250 of the PSTN 200 can be connected to the radio telephones 150 via the cellular radio system 100.

Figure 2 is a cell map illustrating a frequency re-use plan for idealized hexagonal cells 160 of the cellular radio system 100. Thirteen idealized hexagonal cells 160 are illustrated, each divided into three tiers 162, 164, 166. An inner tier 162 of each cell 160 is allocated a first group of 5 frequency division multiplexed traffic channels designated as group 1 in Figure 2. The traffic channels of the first group are transmitted at a low power so that they can be re-used in every hexagonal cell 160 without excessive interference between adjacent cells. Consequently, the re-use rate for the traffic channels of the first group is unity.

A middle tier 164 of each cell 160 is allocated a second group of 10 frequency division multiplexed traffic channels. The traffic channels of the second group can be transmitted at a higher power than the traffic channels of the first group and consequently can only be re-used once in every group of four cells to avoid excessive interference between adjacent cells (i.e. at a re-use rate of $1/4$). Thus, four different second groups of 10 channels are provided. These are designated as groups 21, 22, 23 and 24 in Figure 2 and are repeated in a four cell pattern 170 which is outlined in heavy lines at the bottom of Figure 2.

Similarly, an outer tier 166 of each cell 160 is allocated a third group of 5 frequency division multiplexed traffic channels which is subdivided into three subgroups. The traffic channels of the third group can be transmitted at a higher power than the traffic channels of the first and second groups. In fact, the outer tiers 166 of adjacent cells overlap (the straight boundaries of the idealized hexagonal cells 160 being only notional boundaries), so that seven different third groups of 5 channels are required, each of which can only be re-used

once in every group of seven cells to avoid excessive interference between adjacent cells (i.e. at a re-use rate of 1/7). The seven different third groups of channels are designated 31, 32, 33, 34, 35, 36, 37 in Figure 2. They
5 are repeated in a seven cell pattern 180 which is outlined in heavy lines at the top of Figure 2.

Figures 3A, 3B and 3C are a flow chart illustrating a first method that can be used by the
10 cellular radio system 100 for allocating a traffic channel to a radio telephone 150. In response to a page received from a base station 130 or in response to a caller initiating a call on the radio telephone 150, the radio telephone 150 detects and seizes an idle control channel
15 and transmits a service request to the base station 130 on the control channel. The base station 130 forwards the service request to a radio telephone switching system 110. The base station 130 also measures the received signal strength on the control channel and transmits a Received
20 Signal Strength Indication (RSSI) to the switching system 110.

The switching system 110 compares the RSSI to a Tier 3 threshold to determine whether a Tier 3 traffic
25 channel is needed to serve the radio telephone 150. For example, if the RSSI is less than -80 dBm, the switching system 110 determines that a Tier 3 channel is needed. If a Tier 3 traffic channel is available in the cell occupied by the radio telephone 150, the switching system 110
30 allocates a Tier 3 traffic channel to the radio telephone 150, sets the base station transmit power for the allocated channel at a Tier 3 power level (e.g. 100 W), and sends a service request response to the radio telephone 150 on the control channel via the base station 130, instructing the
35 radio telephone 150 to tune to the allocated traffic channel and to set its transmit power at a Tier 3 power level (e.g. a VMAC of 0). If no Tier 3 traffic channel is

available in the cell occupied by the radio telephone 150, the switching system 110 sends a service request response to the radio telephone 150 on the control channel indicating that the service request is refused.

5

If the RSSI is greater than the Tier 3 threshold, the switching system 110 determines that a Tier 3 channel is not needed. The switching system 110 compares the received RSSI to a Tier 2 threshold (e.g. -50 dBm) to
10 determine whether a Tier 2 channel is needed. If the RSSI is less than the Tier 2 threshold, a Tier 2 traffic channel is needed, and the switching system 110 checks the availability of Tier 2 channels in the cell occupied by the radio telephone 150. If a Tier 2 traffic channel is
15 available in the cell occupied by the radio telephone 150, the switching system 110 allocates a Tier 2 traffic channel to the radio telephone 150, sets the base station transmit power for the allocated channel at a Tier 2 power level (e.g. 20 W), and sends a service request response to the
20 radio telephone 150 on the control channel via the base station 130, instructing the radio telephone 150 to tune to the allocated traffic channel and to set its transmit power at a Tier 2 power level (e.g. a VMAC of 2).

25

If no Tier 2 traffic channel is available, the switching system 110 checks for the availability of Tier 3 traffic channels in the cell occupied by the radio telephone 150. If a Tier 3 traffic channel is available, the switching system 110 allocates a Tier 3 traffic channel
30 to the radio telephone 150, sets the base station transmit power for the allocated channel at the Tier 2 power level (e.g. 20 W), and sends a service request response to the radio telephone 150 on the control channel via the base station 130, instructing the radio telephone 150 to tune to
35 the allocated traffic channel and to set its transmit power at the Tier 2 power level (e.g. a VMAC of 2). Tier 2 power levels are used even though a Tier 3 channel has been

allocated in order to minimize interference in adjacent cells while providing adequate transmission performance.

If neither Tier 2 nor Tier 3 traffic channels
5 are available in the sector occupied by the radio telephone 150, the switching system 110 sends a service request response to the radio telephone 150 on the control channel indicating that the service request is refused.

10 If the RSSI is greater than the Tier 2 threshold, the switching system 110 determines that a Tier 1 channel will provide adequate transmission performance. The switching system 110 checks the availability of Tier 1 channels in the cell occupied by the radio telephone 150.
15 If a Tier 1 traffic channel is available, the switching system 110 allocates a Tier 1 traffic channel to the radio telephone 150, sets the base station transmit power for the allocated channel at a Tier 1 power level (e.g. 5 W), and sends a service request response to the radio telephone 150
20 on the control channel, instructing the radio telephone 150 to tune to the allocated traffic channel and to set its transmit power at a Tier 1 power level (e.g. a VMAC of 5).

If no Tier 1 traffic channel is available in the
25 cell occupied by the radio telephone 150, the switching system 110 checks for the availability of Tier 2 or Tier 3 traffic channels in the cell occupied by the radio telephone 150. If a Tier 2 or Tier 3 traffic channel is available, the switching system 110 allocates a Tier 2 or
30 Tier 3 traffic channel to the radio telephone 150, sets the base station transmit power for the allocated channel at the Tier 1 power level (e.g. 5 W), and sends a service request response to the radio telephone 150 on the control channel, instructing the radio telephone 150 to tune to the
35 allocated traffic channel and to set its transmit power at the Tier 1 power level (e.g. a VMAC of 5). Tier 1 power levels are used even though a Tier 2 or Tier 3 channel has

been allocated in order to minimize interference in adjacent cells while providing adequate transmission performance.

5 If neither Tier 1 nor Tier 2 nor Tier 3 traffic channels are available in the cell occupied by the radio telephone 150, the switching system 110 sends a service request response to the radio telephone 150 on the control channel indicating that the service request is refused.

10

 In the cellular radio system 100 described above, a total of 80 frequency multiplexed traffic channels are divided into a first group of 5 channels which are re-used in Tier 1 of each cell, 4 different second groups of
15 10 channels each which are re-used in Tier 2 of every fourth cell, and 7 different third groups of 5 channels each which are re-used in Tier 3 of every seventh cell. Consequently, 20 traffic channels are available for use in each cell of the cellular radio system. For a conventional
20 frequency plan in which each channel is re-used once in every 7 adjacent cells, the total number of 80 traffic channels would need to be divided seven ways, so that only 11 or 12 traffic channels would be available for use in each cell. Consequently, the tiering arrangement of the
25 cellular radio system 100 provides a capacity enhancement of approximately 75%.

 Moreover, because the cellular radio system 100 allocates Tier 2 or Tier 3 channels when Tier 1 channels
30 are fully occupied, and allocates Tier 3 channels when Tier 2 channels are fully occupied, the cellular radio system adapts to heavy traffic in central regions of each cell to provide a further effective enhancement to the cell capacity.

35

 Figures 4A, 4B and 4C are a flow chart illustrating a second method that can be used by the

cellular radio system 100 for allocating a traffic channel to a radio telephone 150. In response to a page received from a base station 130 or in response to a caller initiating a call on the radio telephone 150, the radio
5 telephone 150 detects and seizes an idle control channel and transmits a service request to the base station 130 on the control channel. The base station 130 forwards the service request to a radio telephone switching system 110.

10 The switching system 110 allocates a Tier 1 traffic channel to the radio telephone 150 if one is available in the cell occupied by the radio telephone 150. If no Tier 1 traffic channel is available, the switching system 110 allocates a Tier 2 traffic channel, and if no
15 Tier 2 traffic channel is available either, the switching system 110 allocates a Tier 3 traffic channel to the radio telephone 150. In each case, the switching system 110 sets the base station transmit power for the allocated channel at a Tier 1 power level (e.g. 5 W), and sends a service
20 request response to the radio telephone 150 on the control channel, instructing the radio telephone 150 to tune to the allocated traffic channel and to set its transmit power at a Tier 1 power level (e.g. a VMAC of 5). If no traffic channels are available in any of Tiers 1 2 or 3, the
25 switching system 110 sends a service request response to the radio telephone 150 on the control channel, instructing the radio telephone 150 that the service request is refused.

30 The base station 130 monitors signals received on the allocated traffic channel from the radio telephone 150 and sends an RSSI to the switching system 110. The switching system 110 compares the RSSI to a Tier 3
threshold to determine whether a Tier 3 traffic channel is
35 needed to serve the radio telephone 150. If a Tier 3 channel is needed and a Tier 3 traffic channel has already been allocated to the radio telephone 150, the switching

system 110 sets the base station transmit power at the Tier 3 level and instructs the radio telephone 150 to increase its transmit power to the Tier 3 level. If a Tier 3 traffic channel is needed but has not already been allocated, and a Tier 3 channel is available in the cell occupied by the radio telephone 150, the switching system 110 hands the radio telephone 150 off to a Tier 3 traffic channel in the same sector, sets the base station transmit power for the allocated channel at a Tier 3 power level, and sends a service request response to the radio telephone 150 on the control channel, instructing the radio telephone 150 to tune to the allocated traffic channel and to set its transmit power at a Tier 3 power level. If no Tier 3 traffic channel is available in the cell occupied by the radio telephone 150, the switching system 110 sends a service request response to the radio telephone 150 on the control channel indicating that the service request is refused.

If the RSSI is greater than the Tier 3 threshold, the switching system 110 compares the received RSSI to the Tier 1 threshold to determine whether a Tier 2 channel is needed. If the RSSI is less than the Tier 1 threshold, a Tier 2 traffic channel is needed. If a Tier 2 or Tier 3 channel has already been allocated to the radio telephone 150, the switching system 110 sets the base station transmit power at the Tier 2 level and instructs the radio telephone 150 to increase its transmit power to the Tier 2 level. If a Tier 2 or Tier 3 traffic channel has not already been allocated to the radio telephone 150, the switching system 110 checks the availability of Tier 2 channels. If a Tier 2 traffic channel is available in the cell occupied by the radio telephone 150, the switching system 110 hands the radio telephone 150 off to a Tier 2 traffic channel, sets the base station transmit power for the allocated channel at a Tier 2 power level, and sends a service request response to the radio telephone 150 on the

control channel, instructing the radio telephone 150 to tune to the allocated traffic channel and to set its transmit power at a Tier 2 power level.

5 If no Tier 2 traffic channel is available in the cell occupied by the radio telephone 150, the switching system 110 checks for the availability of Tier 3 traffic channels in the cell occupied by the radio telephone 150. If a Tier 3 traffic channel is available, the switching
10 system 110 hands the radio telephone 150 off to a Tier 3 traffic channel, sets the base station transmit power for the allocated channel at the Tier 2 power level, and sends a service request response to the radio telephone 150 on the control channel, instructing the radio telephone 150 to
15 tune to the allocated traffic channel and to set its transmit power at the Tier 2 power level.

 If neither Tier 2 nor Tier 3 traffic channels are available in the cell occupied by the radio telephone
20 150, the switching system 110 sends a service request response to the radio telephone 150 on the control channel indicating that the service request is refused.

 The channel allocation technique illustrated in
25 Figures 4A, 4B and 4C provides the same capacity enhancement benefits as the channel allocation technique illustrated in Figures 3A, 3B and 3C. Moreover, both techniques are fully compatible with TDMA techniques for
 further capacity enhancement.

30 The allocation of 5 of the 80 available traffic channels to the first group of channels, 10 of the 80 available traffic channels to each the four different second groups of channels, and 5 of the 80 available
35 traffic channels to each of the seven different third groups of channels and the base station and radio telephone power settings given for each group of channels are by way

of example only. In a particular application of the cellular radio system 100, the number of traffic channels allocated to each channel group and the optimum power settings for each group of traffic channels would be
5 determined by traffic studies of the particular area to be served by the cellular radio system 100.

The number of groups of traffic channels in each cell may be other than three. A two tier arrangement may
10 be most practical for many applications.

Moreover, the number of traffic channels allocated to each group of channels and the power settings for each group of traffic channels would not necessarily be
15 the same in each cell served by the cellular radio system 100, and the number of groups of traffic channels provided in each cell served by the cellular radio system may vary from cell to cell.

20 Other parameters which are indicative of transmission performance could be measured by the base stations 130 to determine from which group of channels a channel should be allocated to a particular radio telephone
150.

25 In particular, the base stations 130 could monitor a carrier-to-interference ratio or a Bit Error Rate (BER) or a noise level on the control channel and compare that to threshold values to determine from which group of
30 channels a channel should be allocated to a radio telephone 150.

A plurality of transmission performance parameters could be monitored and combined for use in a
35 more complex decision process for determining from which group of traffic channels a traffic channel should be allocated. The transmission performance parameters could

be monitored in either or both directions of transmission (i.e. from the terminal to the base station and from the base station to the terminal). The monitoring could be performed either on the control channel or on a traffic
5 channel, and could be performed continuously or sporadically.

The groups of channels need not be operated at different power levels, and the groups of channels need not
10 map onto tiers having different geographical locations. The channel allocation process would be essentially as shown in Figures 3A, 3B and 3C, except that the steps of setting the base station and radio telephone power levels could be omitted.

15

Similarly, the measured transmission parameter in the channel allocation process shown in Figures 4A, 4B and 4C could be a carrier-to-interference ratio or a BER or a noise level monitored on the initially allocated traffic
20 channel and the steps of setting the base station and radio telephone power levels could be omitted.

In the flow charts of Figures 3A, 3B, 3C and 4A, 4B, 4C, the service request is refused if no suitable
25 traffic channel is available in the serving cell. Upon such service refusal, attempts could be made to provide service from an adjacent cell. Alternatively, the traffic channel allocation process could be retried after a suitable delay.

30

The channel allocation processes described above are also applicable to sectorized cells. For example, Figure 5 is a cell map illustrating a frequency re-use plan for idealized tri-sectorized hexagonal cells 190, each cell 190
35 having three tiers 192, 193, 194 and each tier having three sectors 196, 197, 198. The inner tier 192 of each cell 190 is allocated a first group of frequency division

multiplexed traffic channels which is subdivided into three subgroups 11, 12, 13, one subgroup per sector. The traffic channels of the first group are transmitted at a low power so that they can be re-used in every hexagonal cell without excessive interference between adjacent cells. Consequently, the re-use rate for the traffic channels of the first group is unity.

The middle tier 193 of each cell 190 is allocated a second group of frequency division multiplexed traffic channels which is subdivided into three subgroups. The traffic channels of the second group are transmitted at a higher power than the traffic channels of the first group and consequently can only be re-used once in every group of four cells to avoid excessive interference between adjacent cells (i.e. at a re-use rate of 1/4). Thus, four different second groups are provided, each comprising three different subgroups as follows:

second group 1 comprises subgroups 211, 221, 231;
second group 2 comprises subgroups 212, 222, 232;
second group 3 comprises subgroups 213, 223, 233; and
second group 4 comprises subgroups 214, 224, 234.

Similarly, the outer tier 194 of each cell 190 is allocated a third group of frequency division multiplexed traffic channels which is subdivided into three subgroups. The traffic channels of the third group are transmitted at a higher power than the traffic channels of the first and second groups and consequently can only be re-used once in every group of seven cells to avoid excessive interference between adjacent cells (i.e. at a re-use rate of 1/7). Thus, seven different third groups are provided, each comprising three different subgroups as follows:

third group 1 comprises subgroups 311, 312, 313;
third group 2 comprises subgroups 321, 322, 323;
third group 3 comprises subgroups 331, 332, 333;

third group 4 comprises subgroups 341, 342, 343;
third group 5 comprises subgroups 351, 352, 353;
third group 6 comprises subgroups 361, 362, 363; and
third group 7 comprises subgroups 371, 372, 373.

5

For application to the sectorized cells 190 shown in Figure 5, the processes described above must be modified to search for and allocate traffic channels from a subgroup corresponding to the sector of the cell occupied by the
10 radio telephone 150.

The channel allocation processes illustrated in Figures 3A, 3B and 3C and in Figures 4A, 4B and 4C may be modified to accommodate multiple traffic channel queues as
15 described in US Patent 5,148,548 issued in the names of Paul Meche et al on September 15, 1992 and entitled "Method of Monitoring Cellular Radio Channels to Avoid Adjacent and Co-Channel Interference". The specification of this patent is hereby incorporated by reference.

20

The channel allocation process illustrated in Figures 4A, 4B and 4C may also be modified by evaluating conventional Mobile Assisted Hand Off (MAHO) criteria once it is determined that the allocated Tier 1 channel has
25 inadequate transmission performance. If the MAHO criteria evaluation indicates that the radio telephone 150 could better be served by another sector or cell, the cellular radio system 100 can hand the radio telephone 150 to that other sector or cell where the channel allocation process
30 begins again. However, if the MAHO criteria evaluation indicates that the radio telephone 150 is best served by the currently serving sector or cell, the process of handing the radio telephone 150 off to a higher tier in the currently serving sector or cell is continued as shown in
35 Figures 4A, 4B and 4C.

The capacity enhancement techniques described above may be used in applications in which all of the radio telephones 150 have fixed locations or in applications in which at least some of the radio telephones 150 are mobile.

5 If at least some of the radio telephones 150 are mobile, the radio telephone switching systems 110 must be equipped with functionality for tracking the location of the mobile radio telephones 150 and for handing off mobile radio telephones between cells, tiers of cells and, where cells
10 are sectorized, between sectors of cells. Conventional location tracking is readily adaptable to tiered cells. Traffic channel allocation in response to hand off requests may be handled as service requests in accordance with Figures 3A, 3B, 3C or Figures 4A, 4B, 4C.

15

The radio telephones 150 may be cellular radio handsets for use only with cellular radio systems, or may comprise a conventional landline telephone connected to a radio interface which permits communication between the
20 landline telephone and the cellular radio system.

Figures 6A and 6B are a flow chart showing steps in a channel allocation algorithm according to a third embodiment of the invention. According to this embodiment
25 of the invention, the traffic channels assigned to each cell are divided into a first group of channels having a relatively low re-use frequency and a second group of channels having a relatively higher re-use frequency. All unallocated traffic channels are periodically monitored for
30 noise, and each unallocated traffic channel is assigned to one of three traffic channel queues:

1. unallocated channels of the first group having a monitored level of noise lower than a threshold value are assigned to a Low Probability of Interference (LPI) queue;
- 35 2. unallocated channels of the second group having a monitored level of noise lower than the threshold value are

assigned to a Moderate Probability of Interference (MPI) queue; and

3. unallocated channels of both groups having a monitored level of noise exceeding the threshold value are assigned to a High Probability of Interference (HPI) queue.

The channel allocation method of Figures 6A and 6B is used when a service request in the form of a call initiation or in the form of an intercell handoff is received at a cell. If the service request is due to call initiation, the service request is refused if the current LPI queue length is less a predetermined number of unallocated LPI channels. In this way, some LPI channels are reserved for incoming handoffs from other cells.

15

If the service request is due to an incoming handoff or, in the case of a call initiation, if the LPI queue length exceeds the predetermined number of channels, the RSSI of the requesting terminal measured on the control channel is compared to a Mobile Proximity Threshold (MPT). If the RSSI is less than the MPT, the terminal is near the periphery of the cell and should preferably be allocated a traffic channel from the LPI queue. A traffic channel is allocated from the LPI queue unless none are currently available, in which case a channel is allocated from the MPI queue. If neither LPI nor MPI channels are currently available, a channel is allocated from the HPI queue.

If the RSSI is greater than the MPT, the terminal is near the base station and an MPI channel is likely to provide adequate performance. Referring to Figure 6B, a traffic channel is allocated from the MPI queue unless the queue is empty, in which case a traffic channel is allocated from the LPI queue. If both the MPI queue and the LPI queue are empty, a traffic channel is allocated from the HPI queue. If all three queues are

empty, there are no traffic channels available and the service request must be refused.

The RSSI of each terminal being served by a MPI
5 channel is monitored continuously or periodically. If the
monitored RSSI drops below the MPT, a handoff procedure
shown in Figures 7A and 7B is initiated. If the RSSI is
below the MPT but above the Handoff Threshold (HOTL) of the
10 cell, the terminal is still considered to be within the
cell. If at least one LPI channel is available, a LPI
channel is allocated from the LPI queue and an intracell
handoff from the MPI channel to the allocated LPI channel
is initiated. If no LPI channels are available, a retry is
initiated.

15 If the monitored RSSI is below the HOTL, the
terminal is considered to be outside of the serving cell and
intercell handoff is attempted (see Figure 7B). If the
intercell handoff is unsuccessful and at least one LPI
20 channel is available, a LPI channel is allocated from the
LPI queue and an intracell handoff from the MPI channel to
the allocated LPI channel is initiated in an effort to keep
the call alive. If the RSSI on the allocated LPI channel
then falls below HOTL, another intercell handoff will be
25 triggered. If no LPI channels are available when an
intercell handoff attempt fails, a retry of the intercell
handoff is initiated.

The RSSI of each terminal being served by a LPI
30 channel is also monitored continuously or periodically. If
the monitored RSSI rises above the MPT, an intracell
handoff procedure shown in Figure 8 is initiated. If the
number of channels in the LPI queue is greater than the
number reserved for incoming handoffs, no intracell handoff
35 is required at this time. A retry is initiated in case the
number of channels in the LPI queue has dropped below the

number reserved for incoming handoffs by the time the retry timer expires.

5 If the number of channels in the LPI queue is below the number reserved for incoming handoffs but there are no channels in the MPI queue, an intracell handoff cannot be completed at this time and a retry is initiated.

10 If the number of channels in the LPI queue is below the number reserved for incoming handoffs and channels are available in the MPI queue, a channel is allocated from the MPI queue, an intracell handoff from the LPI channel to the MPI channel is initiated, and the LPI channel is returned to the LPI queue when the handoff is
15 complete. Consequently, another LPI channel is made available for incoming handoffs.

The embodiments described above may be modified without departing from the principles of the invention, the
20 scope of which is defined by the claims below.

WE CLAIM:

1. A cellular radio system comprising a plurality of base stations, each base station having a first group of channels having a first re-use rate and a second group of channels having a second re-use rate less than the first re-use rate, the cellular radio system being operable upon receipt of a service request for communication with a radio terminal:
 - 10 to monitor a parameter indicative of transmission performance between the terminal and one of the base stations of a channel of the first group of channels of the base station;
 - to allocate a channel of the first group of channels to the terminal when the monitored parameter indicates adequate transmission performance on the channel of the first group of channels and a channel of the first group of channels is available;
 - to allocate a channel of the second group of channels to the terminal when the monitored parameter indicates inadequate transmission performance on a channel of the first group of channels and a channel of the second group of channels is available; and
 - to allocate a channel of the second group of channels to the terminal when the monitored parameter indicates adequate performance on the first group of channels but no channel of the first group of channels is available.
2. A cellular radio system as defined in claim 1,
 - 30 wherein the cellular radio system is operable to monitor a transmission parameter on a control channel between the terminal and the base station, and to infer from the monitored parameter whether transmission performance would be adequate on a channel of the first group of channels.
3. A cellular radio system as defined in claim 1,
 - 35 wherein the cellular radio system is operable:

to allocate a channel of the first group of channels to the terminal upon receipt of the service request when at least one channel of the first group is available;

to monitor a parameter indicative of transmission performance on the allocated channel; and

to re-allocate a channel of the second group of channels to the terminal when the monitored parameter indicates inadequate transmission performance on the allocated channel.

10

4. A cellular radio system as defined in claim 1 wherein:

the monitored parameter is indicative of a signal strength of a radio signal received by the base station from the terminal;

the cellular radio system allocates a channel of the first group of channels when the monitored parameter is greater than a threshold value and a channel of the first group of channels is available; and

the cellular radio system allocates a channel of the second group of channels when the monitored parameter is less than a threshold value.

5. A cellular radio system as defined in claim 4, wherein

the channels of the first group of channels are operated at a first power level;

the channels of the second group of channels are operated at a first power level when allocated in response to no channels of the first group of channels being available and the monitored parameter is greater than the threshold value; and

the channels of the second group of channels are operated at a second power level greater than the first power level when the monitored parameter is less than the threshold value.

6. A cellular radio system as defined in claim 1, wherein: the monitored parameter is indicative of a signal quality of a signal received by the base station from the terminal;

5 the cellular radio system allocates a channel of the first group of channels when the monitored parameter is greater than a threshold value and a channel of the first group is available; and

10 the cellular radio system allocates a channel of the second group of channels when the monitored parameter is less than the threshold value.

7. A cellular radio system as defined in claim 6, wherein the monitored parameter is a carrier-to-
15 interference ratio.

8. A cellular radio system as defined in claim 6, wherein the monitored parameter is a bit error rate.

20 9. A cellular radio system as defined in claim 1, wherein:

at least one base station has at least one further group of channels having a re-use rate less than the second re-use rate;

25 the cellular radio system is operable to allocate a channel of the further group of channels to the terminal when the monitored parameter indicates inadequate transmission performance on channels of both the first and second groups of channels; and

30 the cellular radio system is operable to allocate a channel of the further group of channels to the terminal when no channels of the first and second groups of channels are available.

35 10. A cellular radio system as defined in claim 1, wherein:

at least one base station serves a sectorized cell;

the first and second groups of channels are subdivided into a plurality of subgroups; and

each subgroup is allocated to a respective sector of each cell.

5

11. A cellular radio system as defined in claim 1, wherein the cellular radio system is operable upon receipt of a service request for communication with a radio terminal to allocate a channel of the first group of channels to the terminal when the monitored parameter indicates inadequate transmission performance on a channel of the first group of channels but no channels of the second group of channels are available.

15

12. A cellular radio system as defined in claim 1, wherein unallocated channels of the second group are declared to be unavailable to service requests resulting from call initiations when fewer than a predetermined number of channels of the second group of channels are unallocated, said unallocated channels continuing to be made available to service requests resulting from hand-offs.

13. A method for operating a cellular radio system, the cellular radio system comprising a plurality of base stations, each base station having a first group of channels having a first re-use rate and a second group of channels having a second re-use rate less than the first re-use rate, the method comprising responding to receipt of a service request for communication with a radio terminal by:

monitoring a parameter indicative of transmission performance between the terminal and one of the base stations of a channel of the first group of channels of the base station;

allocating a channel of the first group of channels to the terminal when the monitored parameter indicates

adequate transmission performance on the channel of the first group of channels and a channel of the first group of channels is available;

5 allocating a channel of the second group of channels to the terminal when the monitored parameter indicates inadequate transmission performance on the channel of the first group of channels and a channel of the second group of channels is available; and

10 allocating a channel of the second group of channels to the terminal when the monitored parameter indicates adequate performance on the channel of the first group of channels but no channel of the first group of channels is available.

15 14. A method as defined in claim 13, wherein the monitoring step comprises:

monitoring a transmission parameter on a control channel between the terminal and the base station; and

20 inferring from the monitored parameter whether transmission performance on a channel of the first group of channels would be adequate.

15. A method as defined in claim 13, wherein:
the monitoring step comprises:

25 allocating a channel of the first group of channels upon receipt of the service request, when at least one channel of the first group of channels is available; and

30 monitoring a parameter indicative of transmission performance on the allocated channel;
the step of allocating a channel of the first group of channels when the monitored parameter indicates adequate transmission performance comprises maintaining the allocation performed on receipt of the service request when
35 the monitored parameter indicates adequate transmission performance; and

the step of allocating a channel of the second group of channels to the terminal when the monitored parameter indicates inadequate transmission performance comprises re-allocating a channel of the second group of channels to the terminal when the monitored parameter indicates inadequate transmission performance.

16. A method as defined in claim 13, wherein:
the monitoring step comprises monitoring a parameter indicative of a signal strength of a radio signal received by the base station from the terminal;
the step of allocating a channel of the first group of channels comprises allocating a channel of the first group of channels when the monitored parameter is greater than a threshold value and a channel of the first group of channels is available; and
the step of allocating a channel of the second group of channels comprises allocating a channel of the second group of channels when the monitored parameter is less than a threshold value.

17. A method as defined in claim 16, further comprising:
operating the channels of the first group of channels at a first power level;
operating the channels of the second group of channels at the first power level when allocated in response to no channels being available and the monitored parameter is greater than the threshold value; and
operating the channels of the second group of channels at a second power level greater than the first power level when the monitored parameter is less than the threshold value.

18. A method as defined in claim 13, wherein:

the monitoring step comprises monitoring a parameter indicative of signal quality of a radio signal received by the base station from the terminal;

5 the step of allocating a channel of the first group of channels comprises allocating the channel of the first group of channels when the monitored parameter is greater than a threshold value and a channel of the first group of channels is available; and

10 the step of allocating a channel of the second group of channels when the monitored parameter indicates inadequate transmission performance comprises allocating a channel of the second group of channels when the monitored parameter is less than the threshold value.

15

19. A method as defined in claim 18, wherein the step of monitoring a parameter indicative of signal quality comprises monitoring a carrier-to-interference ratio.

20 20. A method as defined in claim 18, wherein the step of monitoring a parameter indicative of signal quality comprises monitoring a bit error rate.

21. A method as defined in claim 13, wherein the
25 each base station has at least one further group of channels having a re-use rate less than the second re-use rate, the method further comprising:

allocating a channel of the further group of channels to the terminal when the monitored parameter indicates
30 inadequate transmission performance on channels of both the first and second groups of channels; and

allocating a channel of the further group of channels to the terminal when no channels of the first and second groups are available.

35

22. A method as defined in claim 13, wherein:

at least one base station serves a sectorized cell, the first and second groups of channels are subdivided into a plurality of subgroups, and each subgroup is allocated to a
5 respective sector of each cell;

the step of allocating a channel of the first group of channels to the terminal comprises allocating a channel of a subgroup of the first group of channels, said subgroup being allocated to a sector occupied by the terminal; and

10 the step of allocating a channel of the second group of channels to the terminal comprises allocating a channel of a subgroup of the second group of channels, said subgroup being allocated to a sector occupied by the terminal.

15

23. A method as defined in claim 13, further comprising allocating a channel of the first group of channels to the terminal when the monitored parameter indicates inadequate transmission performance on a channel
20 of the first group of channels but no channels of the second group of channels are available.

24. A method as defined in claim 13, wherein unallocated channels of the second group are declared to be
25 unavailable to service requests resulting from call initiations when fewer than a predetermined number of channels of the second group of channels are unallocated, said unallocated channels continuing to be made available to service requests resulting from hand offs.

30

25. A method for operating a cellular radio system, the cellular radio system comprising a plurality of base stations, each base station having a first group of channels having a first re-use rate and a second group of
35 channels having a second re-use rate less than the first re-use rate, the method comprising responding to receipt of a service request for communication with a terminal by:

allocating a channel of the second group of channels to the terminal when a channel of the second group of channels is available; and

5 monitoring a parameter indicative of transmission performance between the terminal and one of the base stations of a channel of the first group of channels and allocating a channel of the first group of channels to the terminal when the monitored parameter indicates adequate transmission performance on the channel of the first group
10 of channels and no channel of the second group of channels is available.

26. A method as defined in claim 25, wherein unallocated channels of the second group are declared to be
15 unavailable to service requests resulting from call initiations when fewer than a predetermined number of channels of the second group of channels are unallocated, said unallocated channels continuing to be made available to service requests resulting from hand offs.

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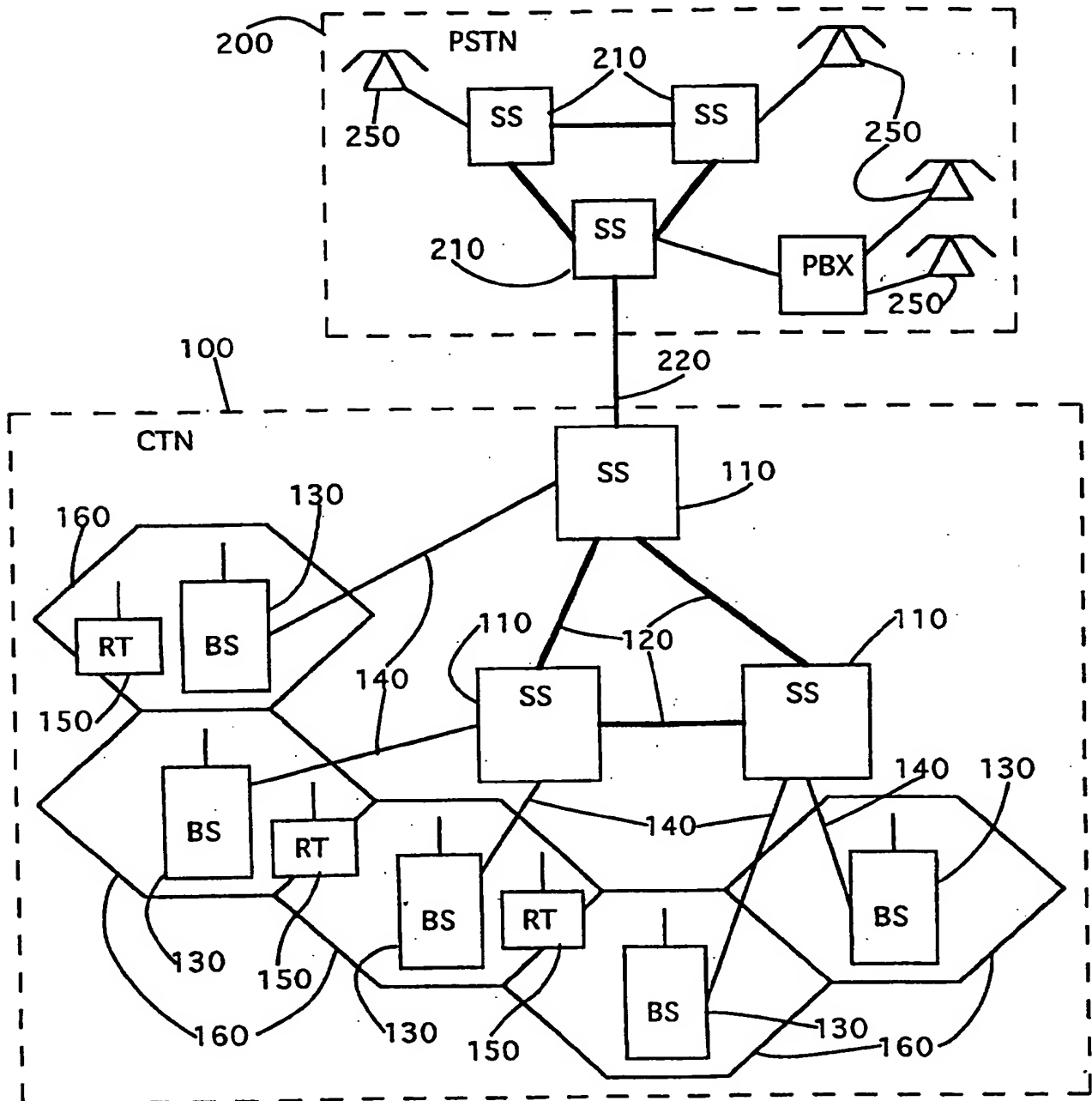


Fig. 1

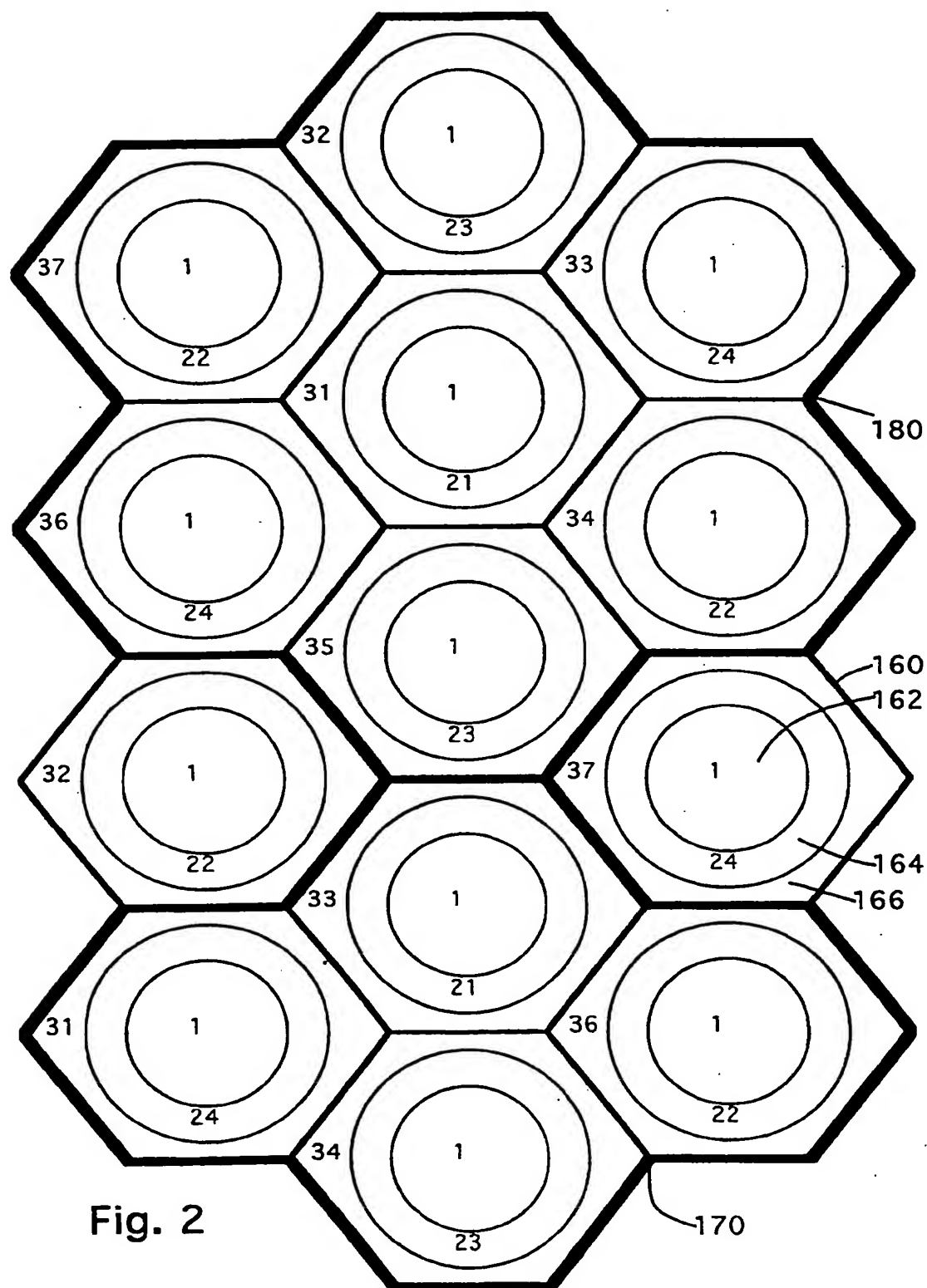


Fig. 2

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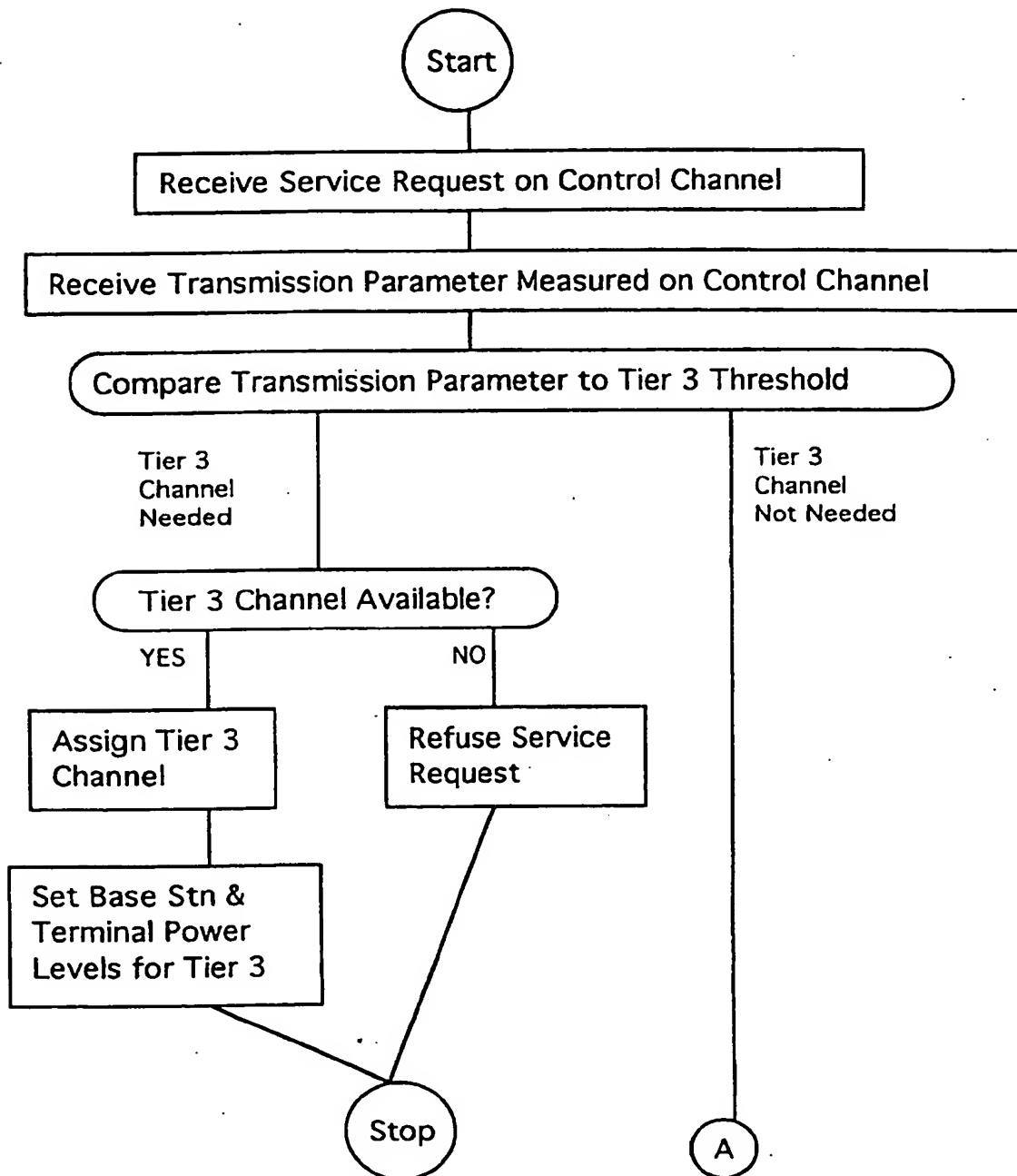


Fig. 3A

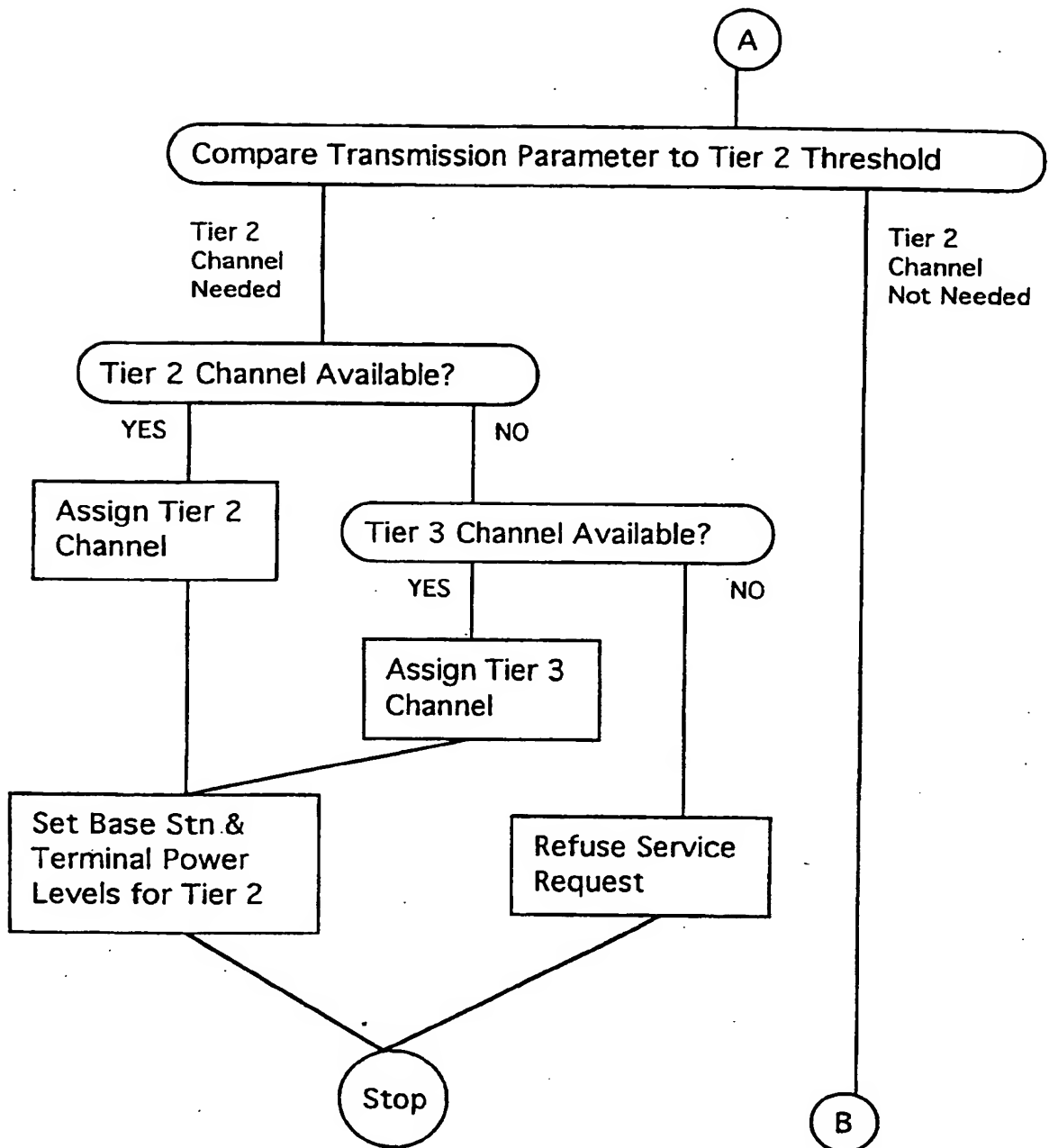


Fig. 3B

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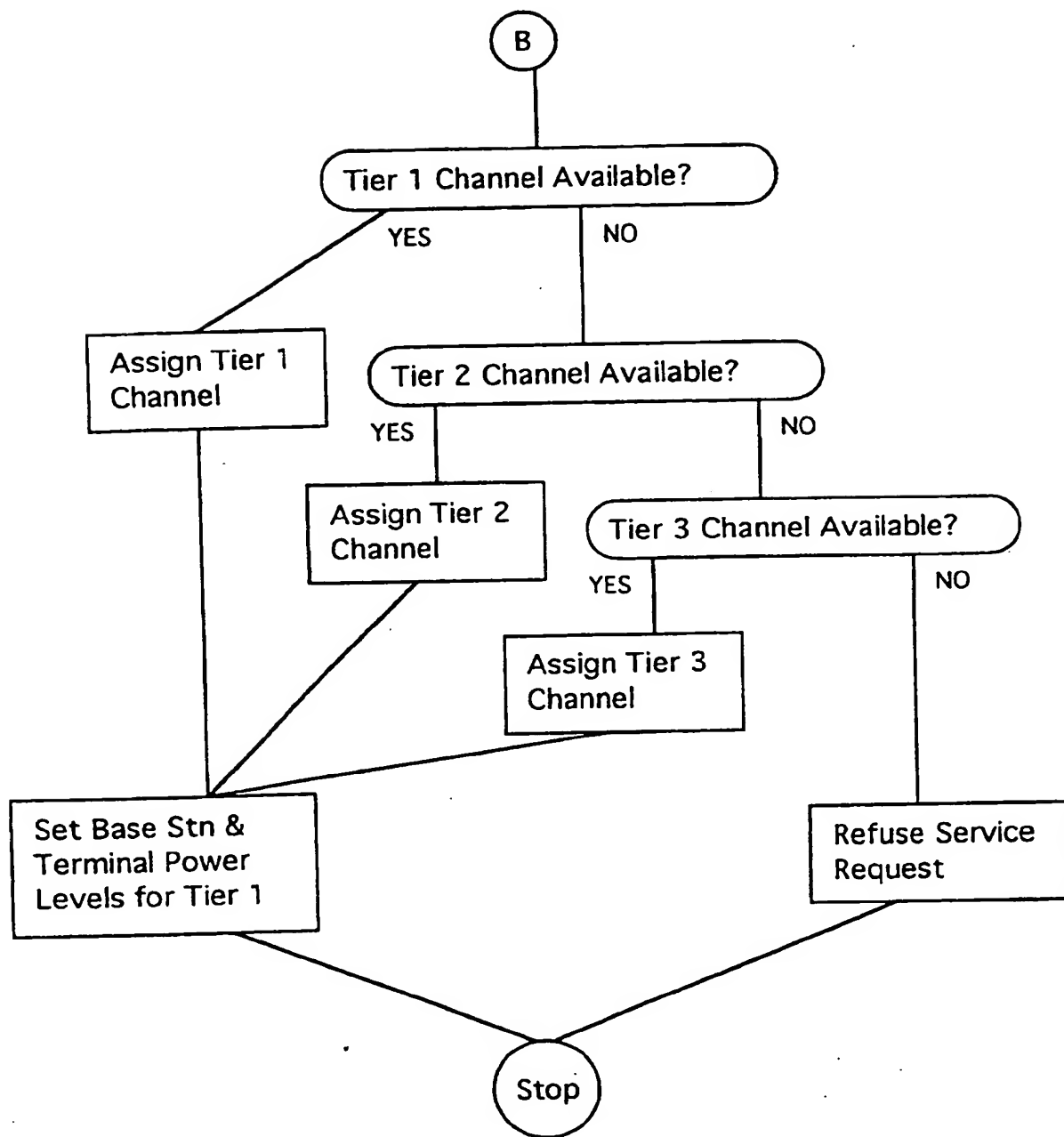


Fig. 3C

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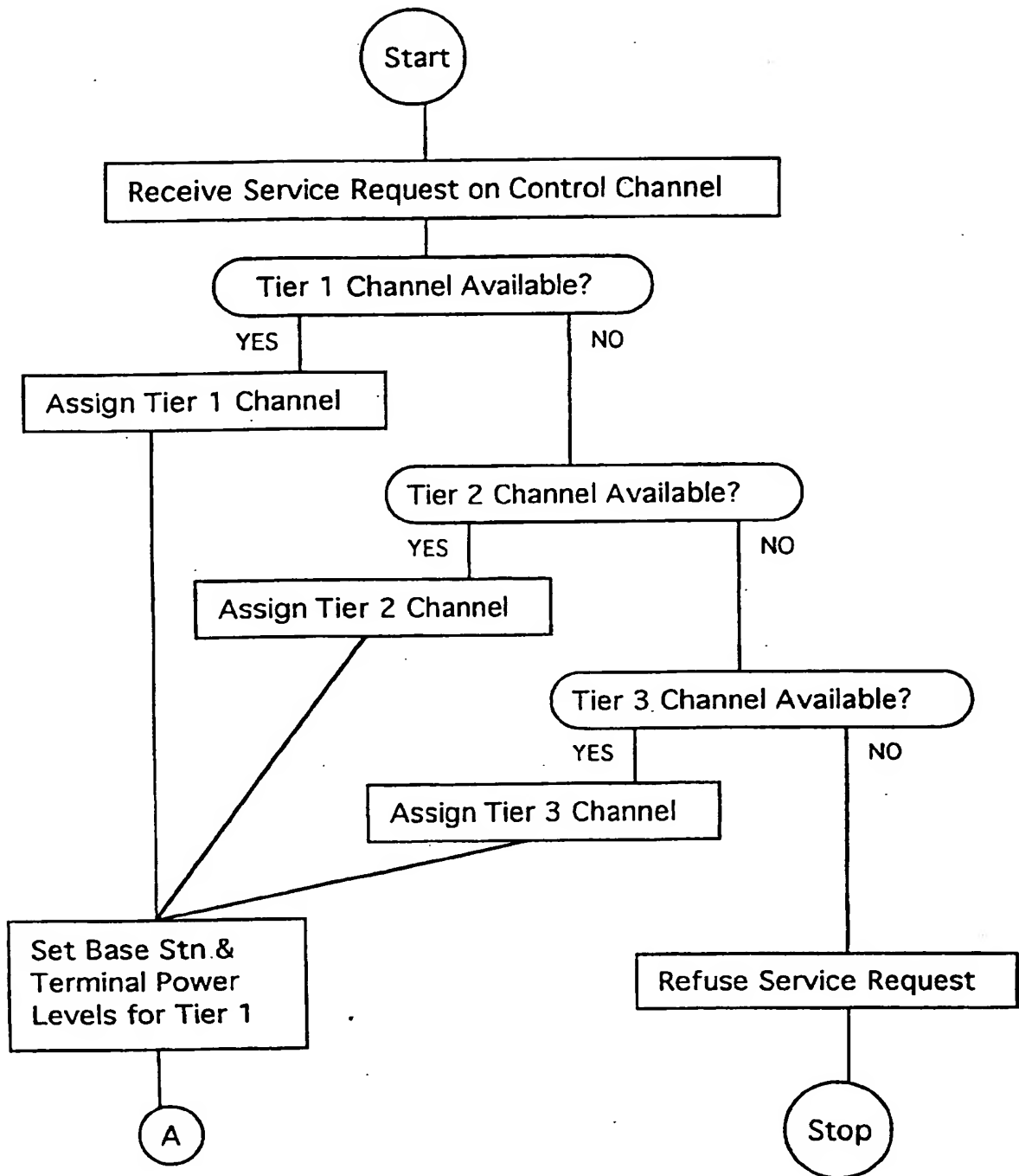


Fig. 4A

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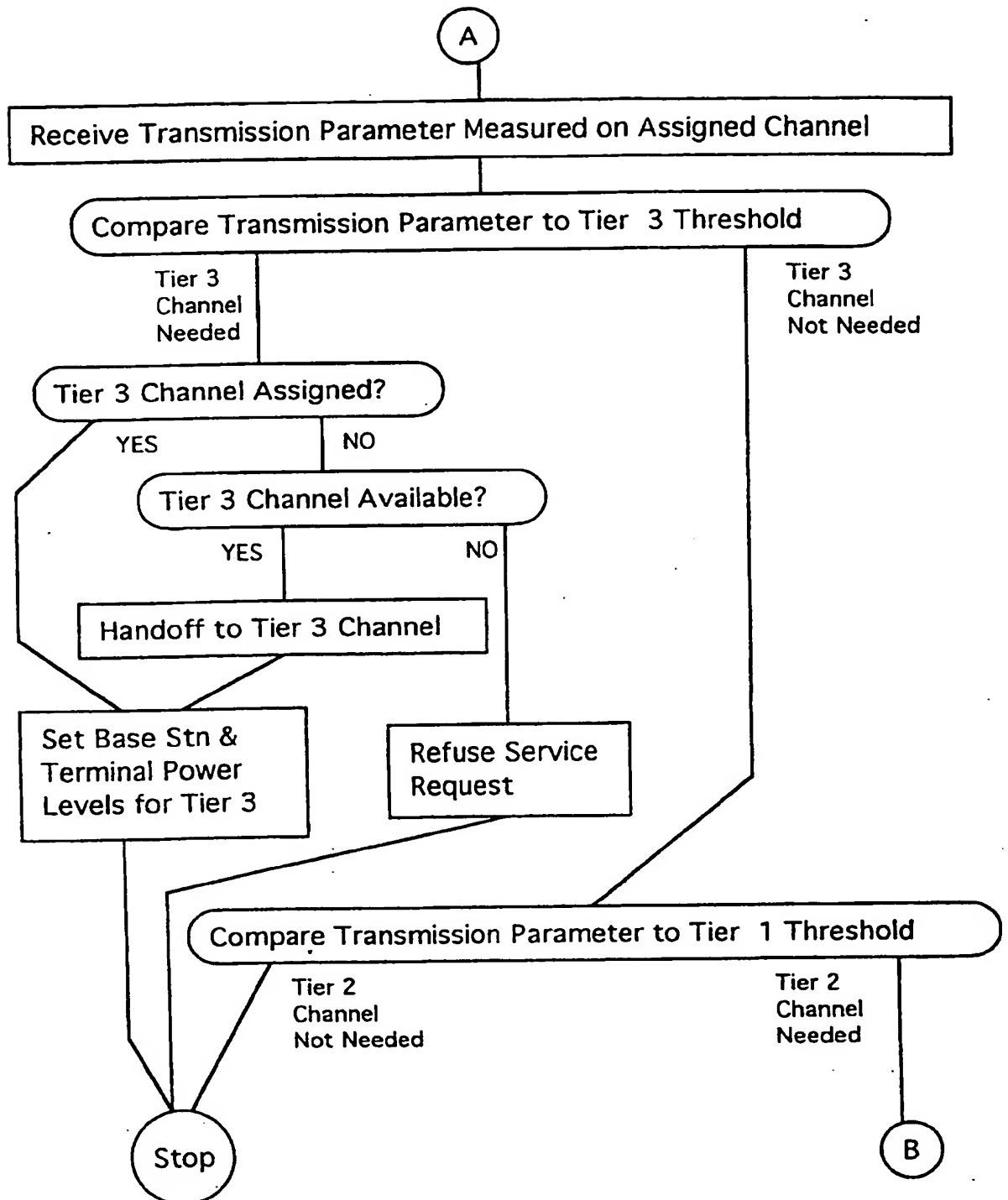


Fig. 4B

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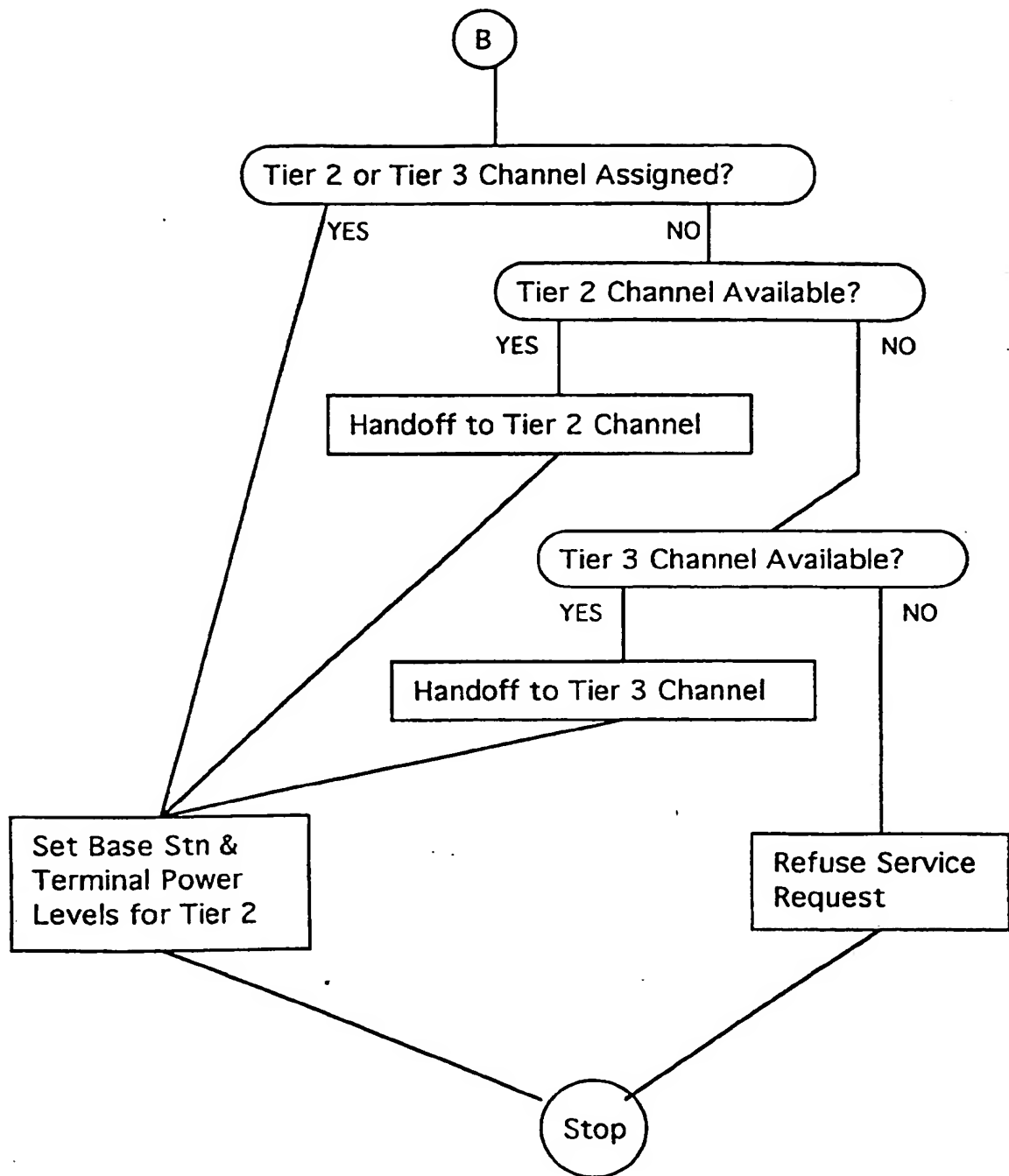
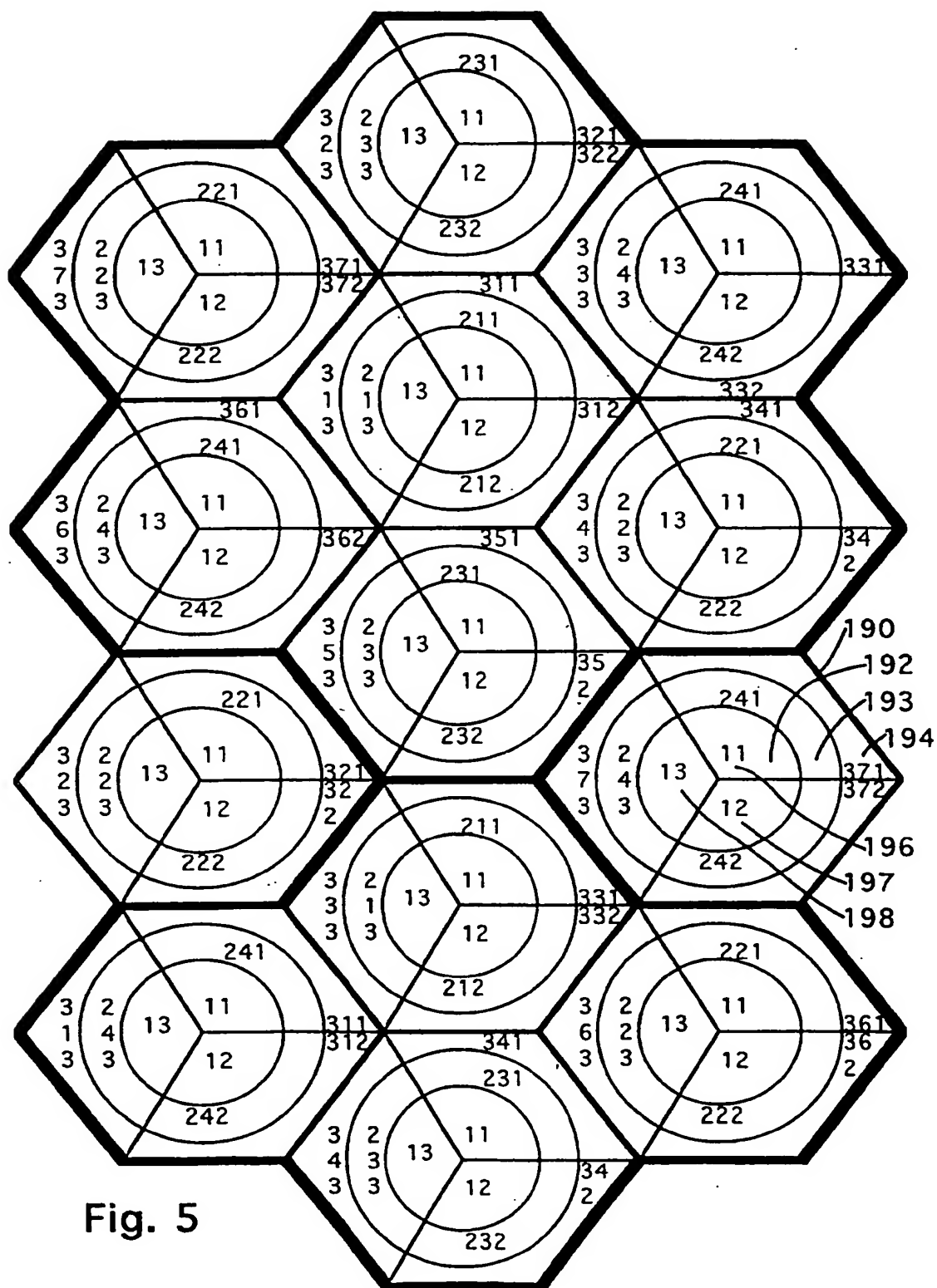


Fig. 4C

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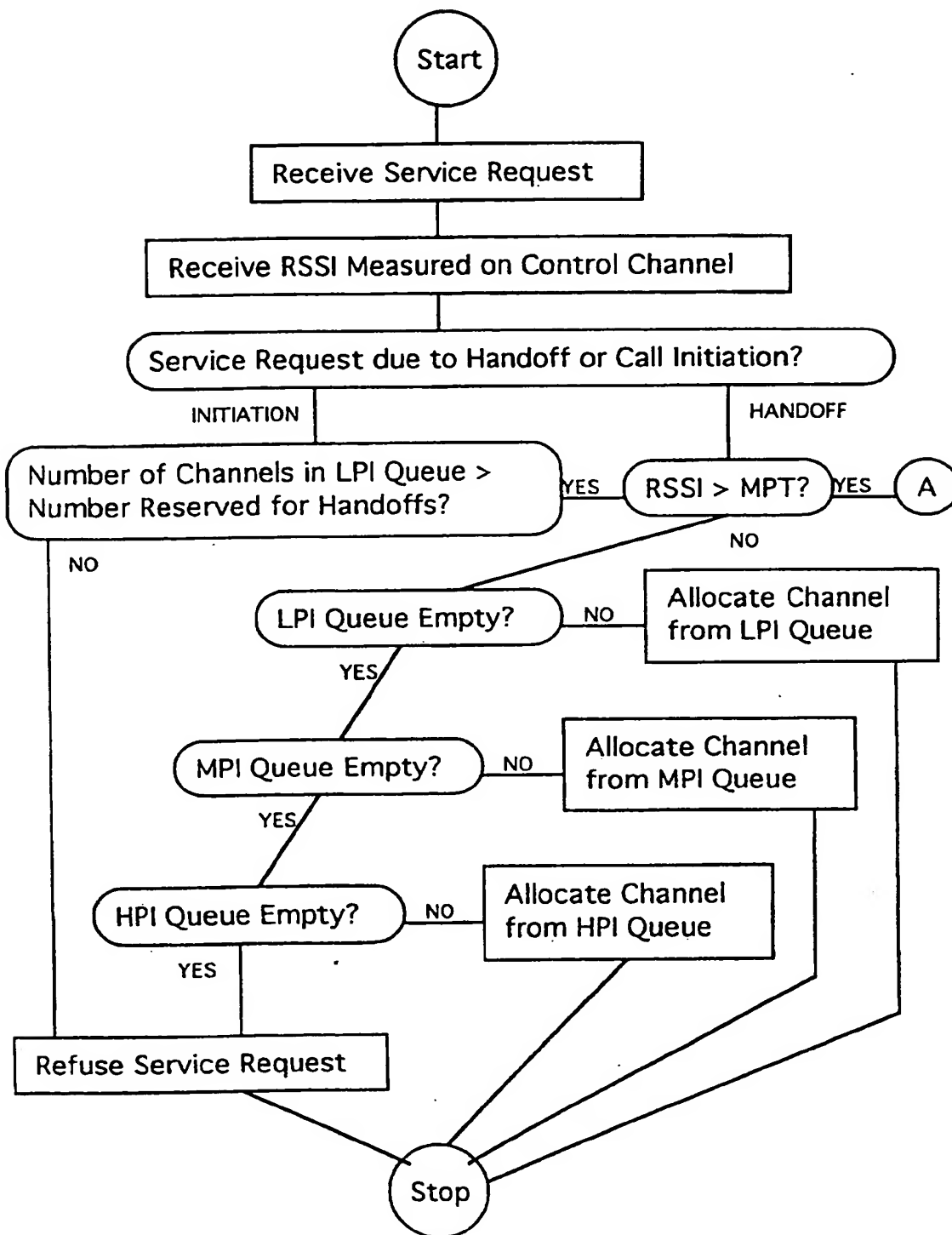


Fig. 6A

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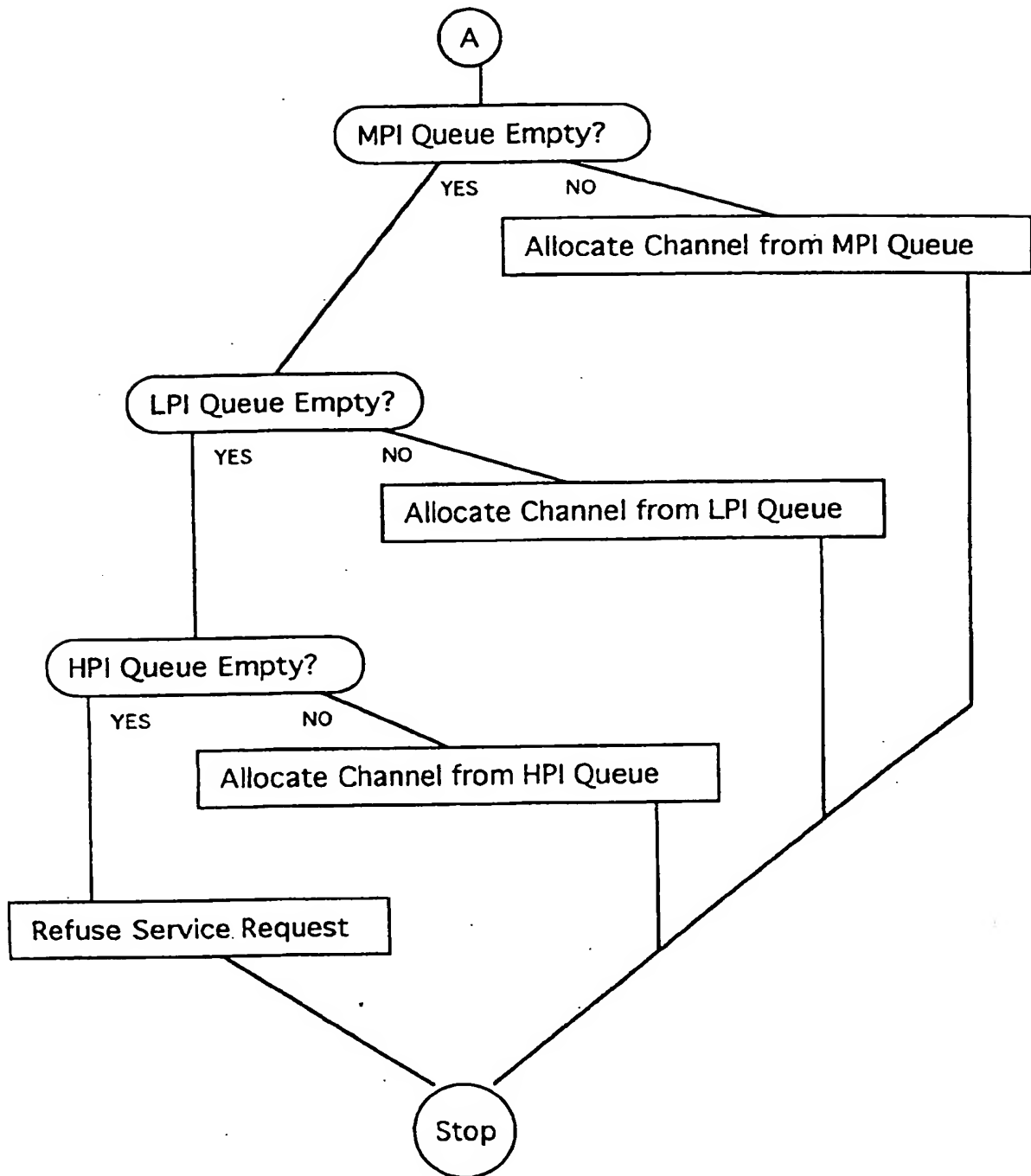


Fig. 6B

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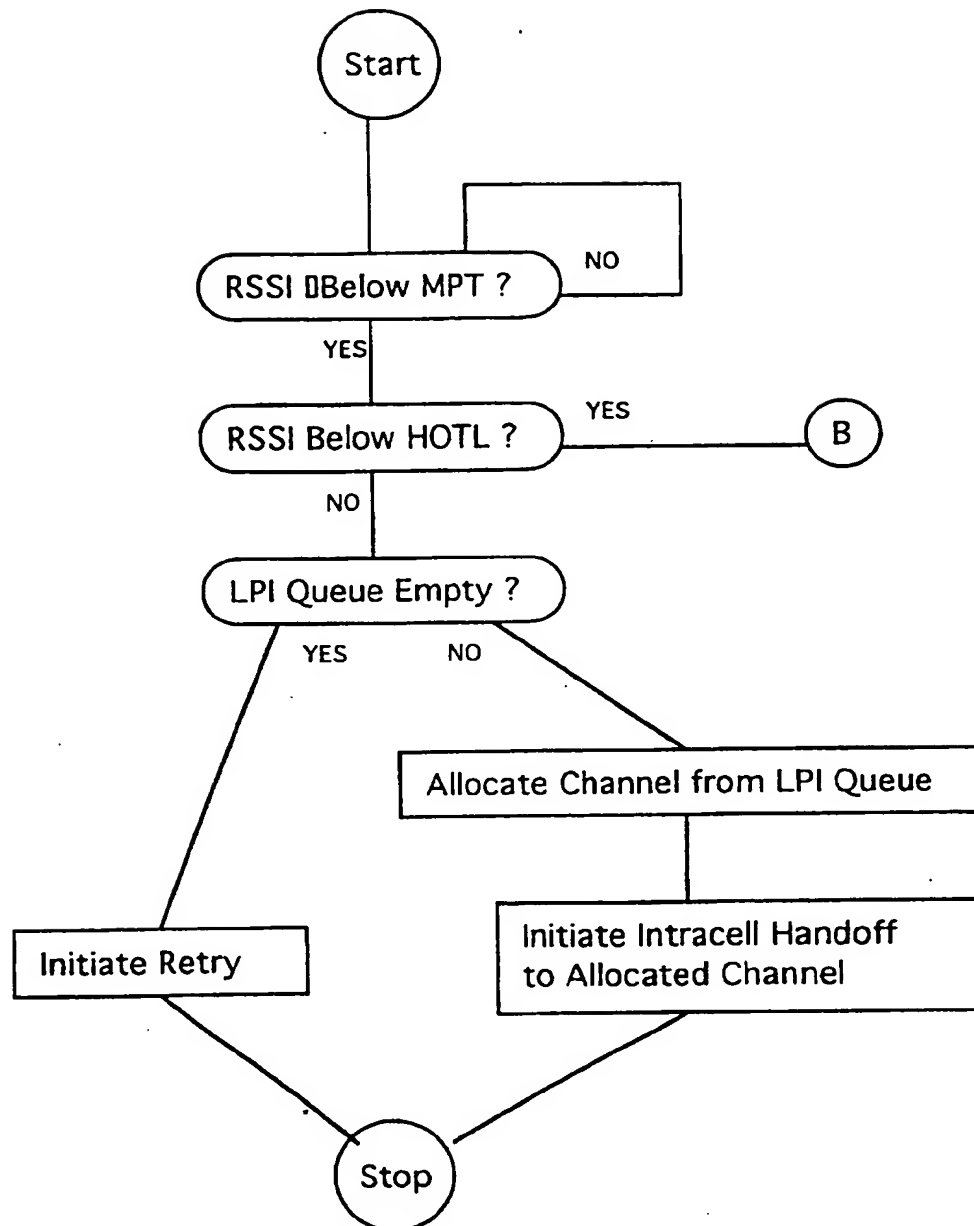


Fig. 7A

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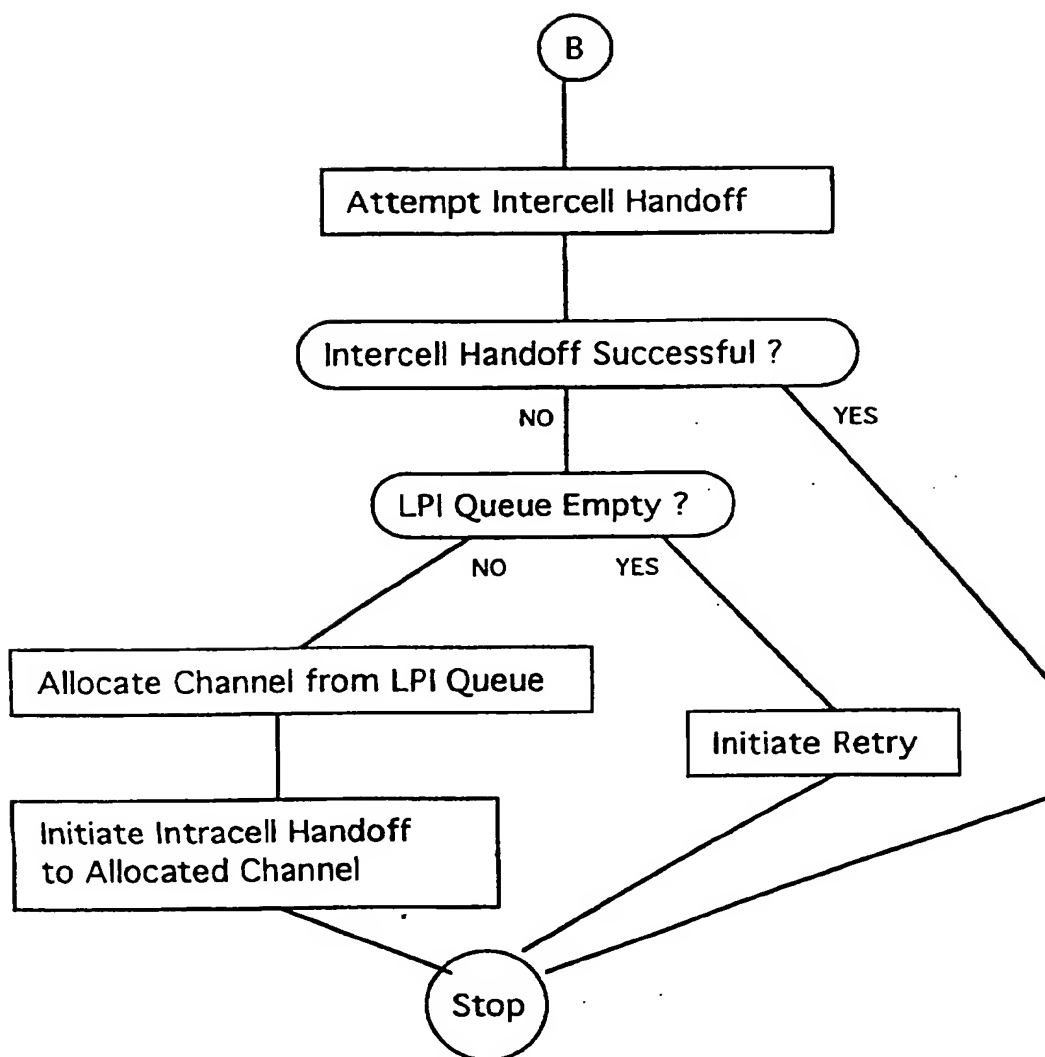


Fig. 7B

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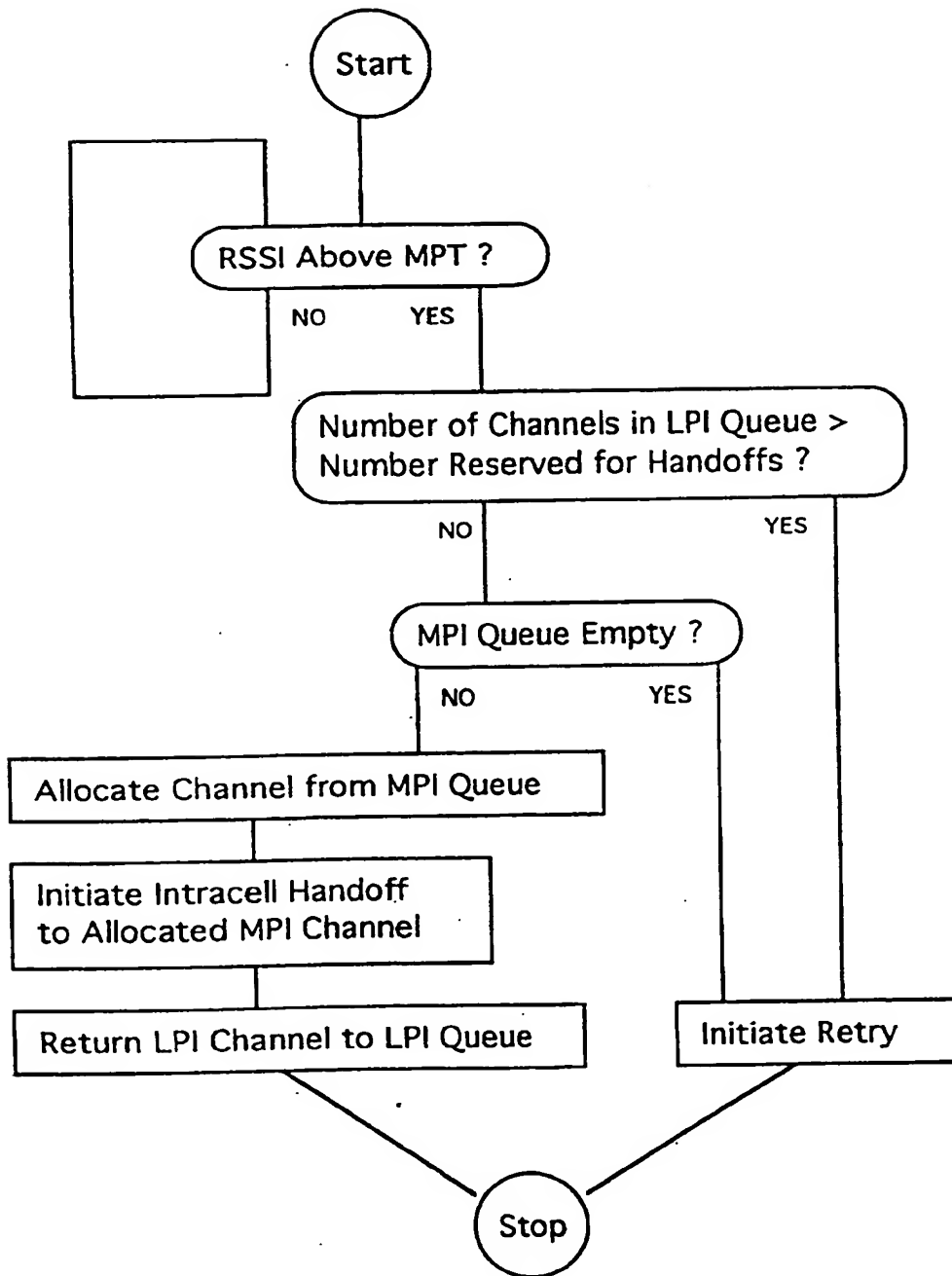


Fig. 8

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